8-2024

Using Artificial Intelligence to Improve and Accelerate the Breeding Process for Root Structure Architecture in Alfalfa

Brandon J. Weihs

Jo Heuschele

Zhanyou Xu

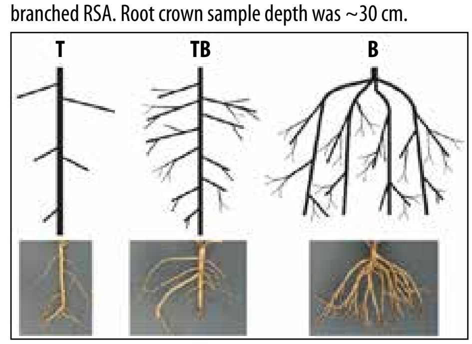
Using Artificial Intelligence to Improve & Accelerate the Breeding Process for Root System Architecture in Alfalfa

Brandon Weihs, Jo Heuschele, Zhanyou Xu, USDA-ARS-PSRU

Yields for alfalfa, the world's most popular forage crop, have declined over the last ~50 years, and breeders, farmers, and other stakeholders are interested in breaking the yield bottleneck in innovative ways, such as with root system improvements and state-of-the-art methods including artificial intelligence (AI).

The Green Revolution of the 20th century brought improvements to agriculture largely in aboveground plant characteristics leading to maximized yields, especially for small grains. Agriculture is currently in the "second" Green Revolution, and breeders and plant scientists are especially interested in making improvements to plant root traits and root system architecture (RSA) because roots are mineral, water, and nutrient acquisition organs of most plants, and because they foster symbiotic relationships with soil organisms.

Figure 1. Actual and simulated alfalfa RSAs. Top row are simulated roots. Bottom row shows different alfalfa RSA types bred at the USDA-ARS-PSRU in St. Paul, MN. "T" represents taproot RSA. "TB" represents intermediate RSA. "B" represents branched RSA. Root crown sample depth was ~30 cm.



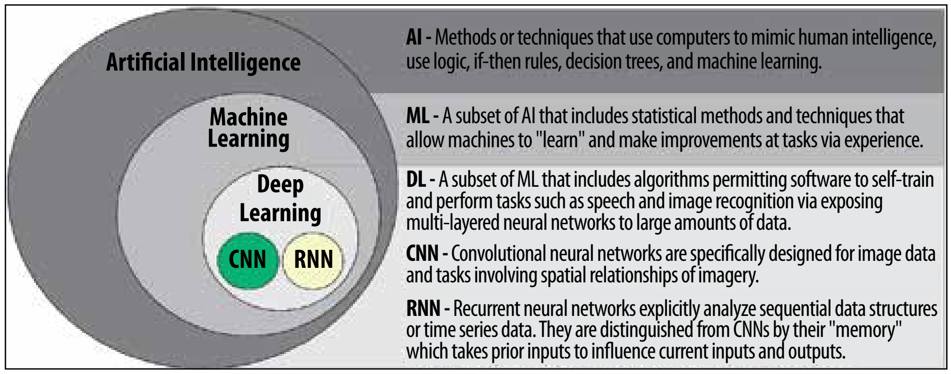
Increasing stress tolerance for acidity, salinity, drought, encasement, and heaving will undoubtedly increase yield potential while requiring lower inputs and formerly marginal or nonarable lands will support the newly created lines. For alfalfa, improvements in low pH soil tolerance have potential to open millions of acres in the U.S. to new agriculture (in 2022 ~6 million hectares of alfalfa were grown in the U.S. for hay), especially in the East where soil acidity has historically excluded widespread cultivation of alfalfa. Like breeding for increased stress tolerances, improving the ability of root systems to access water and/or nutrients are also being investigated to break the decades-long alfalfa yield bottleneck. Breeding for specific root types, or ideotypes, can achieve a variety of goals in different settings. For example, in areas that experience drought or low water inputs, deep, low fibrous, taproot-type ("T" in Figure 1) root system architectures (RSAs) capable of accessing ground water may be desirable. The same taproot RSA may also be used as an atmospheric pollution remediating plant to sequester CO_2 deep into soils. For low-phosphorus soils, a denser RSA that has abundant branching (daughter roots) and high amounts of fibrous root materials able to forage more thoroughly for nutrients higher in the soil column may be desired. The ability to create "designer roots" tailored to their environmental settings have enormous potential and wide appeal to stakeholders and farmers.

With these needs and goals in mind, the USDA-ARS Plant Science Research Unit (PSRU) in St. Paul, MN, has been conducting research pairing root image data with AI image analysis models to improve the breeding and selection process for genetic lines with specific RSAs. Recently, they paired alfalfa root crown image data with an award-winning deep learning model, called ResNet-18 that performed well, with an overall prediction accuracy of ~75%. Future employment of that model on new imagery will speed up the next root selections because the image capture and model-driven classification will happen instantaneously whereas manual measurements and classifications are much slower and have high potential to include errors and/or bias. Increased selection speed results in faster achievement of breeding goals and implementation of those genetics into the fields of alfalfa farmers.

The use of AI has exploded in recent years, spreading into every possible application imaginable, and examples such as autofill in text editors, self-driving vehicles, and image analysis of medical images in search of cancer are illustrative of the breadth, wide appeal, and expanding uses of AI in modern times. Because of the many benefits AI provides, plant scientists have also turned their attention to this high-powered suite of tools.

Artificial intelligence is designed to mimic human intelligence with methods or techniques such as logic or machine learning. Machine learning is a subset of AI involving training models or algorithms to "learn" the way humans learn, which involves being exposed to data then asking the model to interpret it based on its training. When a model is sufficiently trained to perform at a desired accuracy, the model is considered validated, and its results can be relied on. The main strengths of AI that have championed it over many human-driven processes are speed and accuracy. The speed of computer-based computations and analyses is not new to science, however, the processes such as counting or observing a sample were formerly impossible tasks for a CPU and were only possible to achieve by humans capable of higher-order logic and the learning process. The USDA-ARS-PSRU is currently investigating some of the many applications of machine learning and deep learning to plant science research, specifically on alfalfa root system architecture, stem cross section morphology, and flower detection for maturity estimations. These multiple efforts that employ AI are aimed at making plant trait improvements related to biomass yield, forage digestibility, and winter survival. AI provides a new approach that is a faster, more-reliable means of data collection and analysis to attain breeding goals.

Figure 2. The subfields of artificial intelligence.



Growers with the power of AI analyses in the field could be able to perform a host of new tests on their stands such as quantifying root mass or depth (for a carbon credit or subsidy) or for determining hay quality and yield in real-time to maximize profits or feed quality. AI-driven image analyses of alfalfa RSAs is a major leap forward for breeding efforts interested in maximizing plant productivity and yields in regional or site-specific environmental settings. For planning desired crop outcomes, future alfalfa variety information may include RSA classifications like the crop characteristics currently listed (fall dormancy, winter survival, and pest and disease resistances).

Further information about AI-driven Image analyses and RSA - spj.science.org/doi/10.34133/plantphenomics.0178.